Updated NNLO PDFs and the standard candle benchmarks

S.Alekhin (*DESY & IHEP, Protvino*)
in collaboration with J.Blümlein and S.Moch (DESY)

- Theory:
  - improved heavy-quark threshold corrections
  - running masses in the FFN and VFN schemes
- Data:
  - low-energy H1 data
  - jet Tevatron data
- α_s and the high-twists
- Summary

DIS2011, Newport News, 12 Apr 2011

The ABM fit ingredients

DATA:

- DIS NC inclusive
- DIS μμ CC production
- fixed-target DY
- Tevatron Run II jets

QCD:

- NNLO evolution
- NNLO massless DIS and DY coefficient functions
- NLO+ massive DIS coefficient functions
  - (NLO + NNLO threshold corrections, running mass)
- NLO jet production corrections

Deuteron corrections in DIS:

- Fermi motion
- off-shell effects

Power corrections in DIS:

- target mass effects
- dynamical twist-4 terms

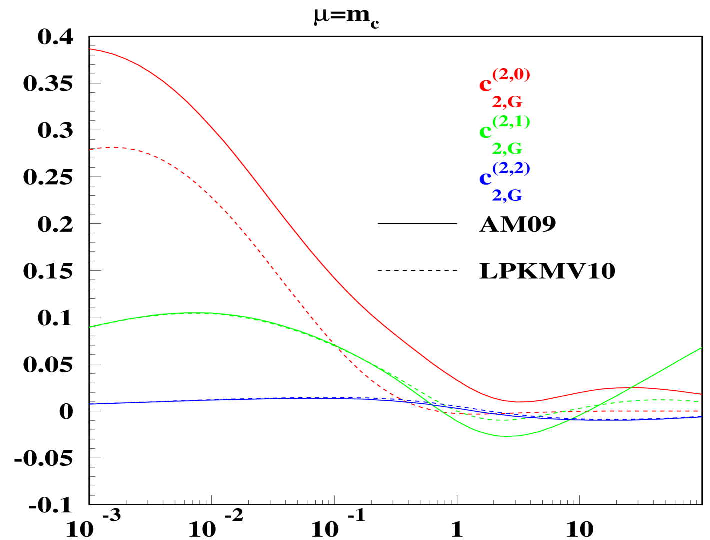
Heavy quark electro-production in FFNS

- Only 3 light flavors in the initial state are considered.
- Accurate at $Q \sim m_c$
- At large Q the fixed-order results may be insufficient due to big logs $\sim ln^n(Q/m_c)$
- The threshold NNLO corrections are available with full tower of $\ln^{2n}(\beta)$

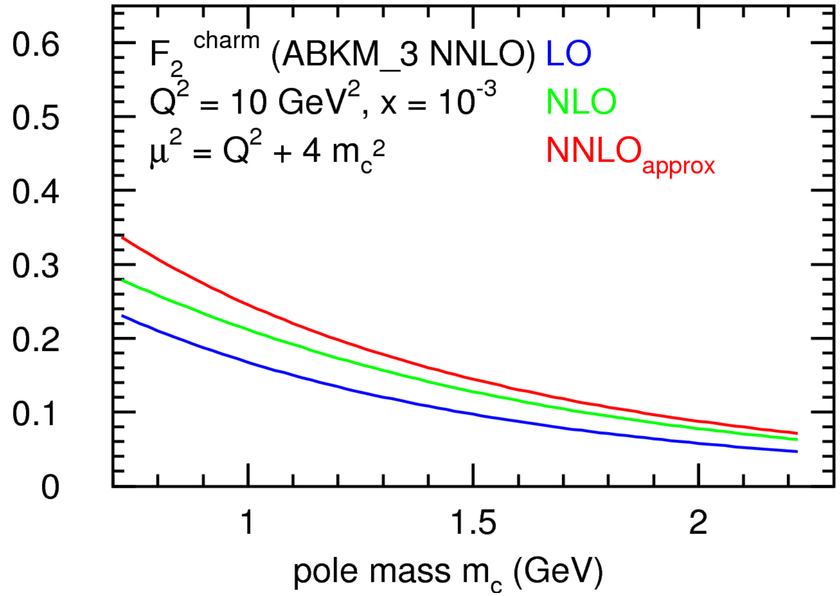
Lo Presti, Kawamura, Moch, Vogt [hep-ph 1008.0951]

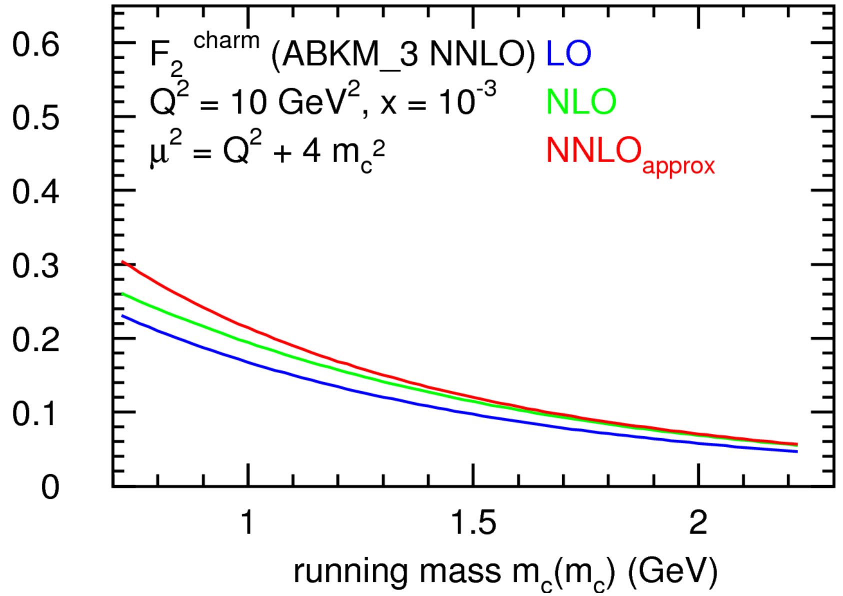
- Running-mass definition for the heavy-quark production

sa, Moch [hep-ph 1011.5790]



F_2^c gets somewhat smaller at small Q and somewhat bigger at large Q



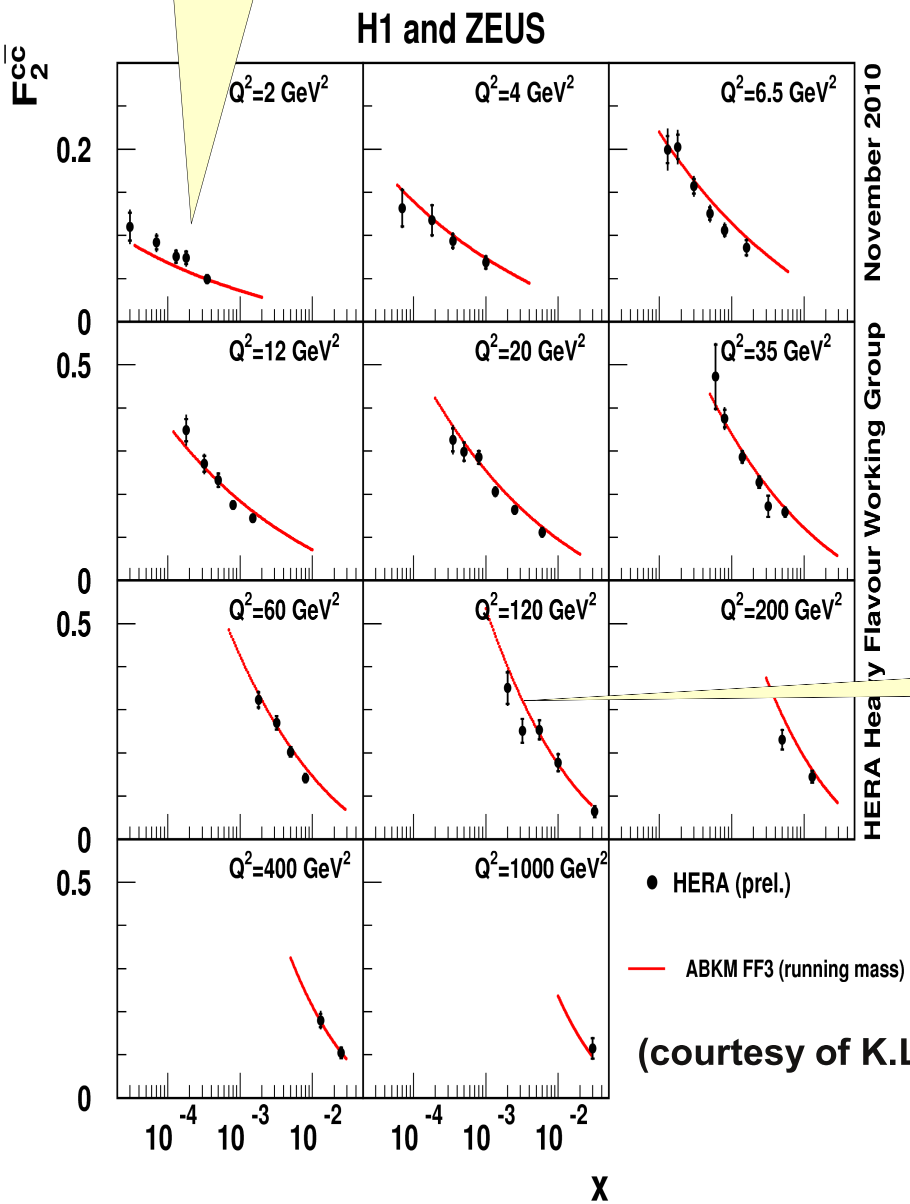


Improved perturbative stability in the running-mass scheme

c-quark production

The NNLO(approx.) FFNS ABM ***predictions*** based on the running mass definition are In nice agreement with the new HERA data

N^3LO corrections?



(courtesy of K.Lipka)

$m_c(m_c)$=1.27±0.08 GeV (PDG '10)

$m_c(m_c)$=1.18±0.06 GeV (incl.F_2 +PDG)

The HERA data prefer $m_c(m_c)$ close to the PDG value

Improved accuracy due to correlation between quark and gluon PDFs must be reduced

No need of the resummation

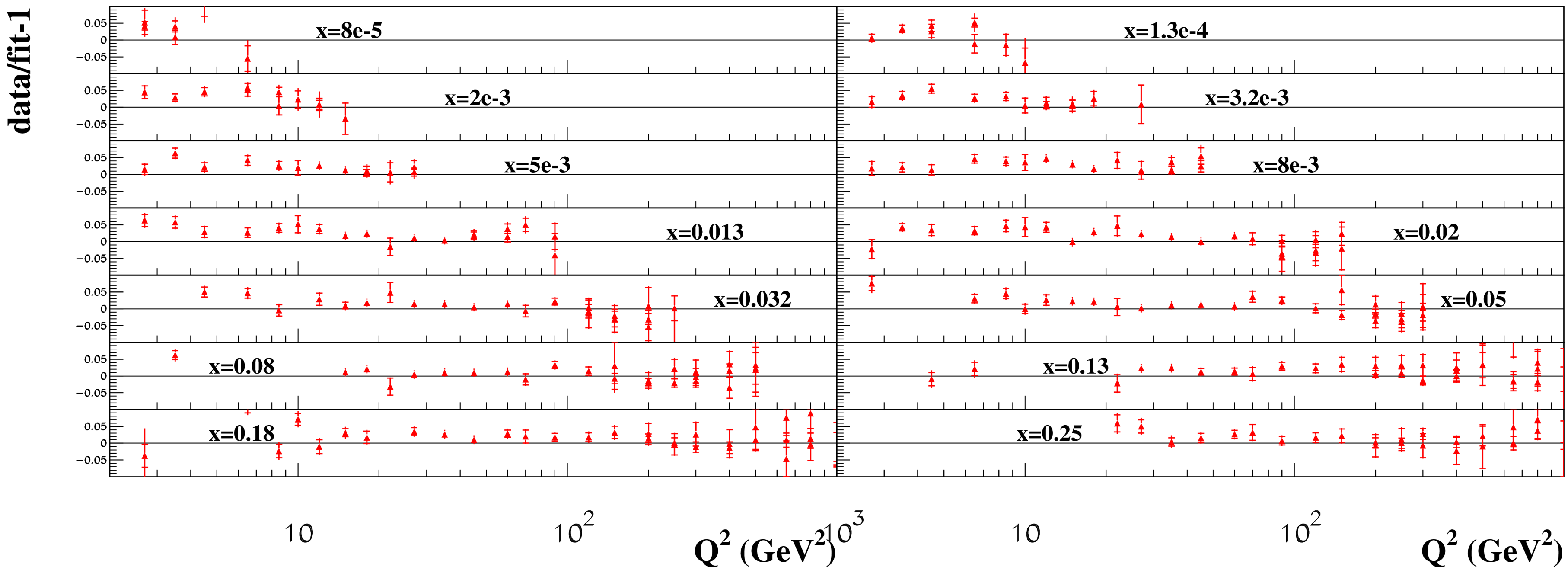
At $Q >> m_c$ first Mellin NNLO moments are known

Ablinger at al. NPB 844, 26 (2011)

Bierenbaum, Blümlein, Klein NPB 829, 417 (2009)

Combined RunI HERA data

H1 and ZEUS Collaborations JHEP 1001, 109 (2010)



- The PDF shape was modified to accommodate new data

$$xS(x) = exp\left[a \ln x(1+\beta \ln x)(1+\gamma_1 x)\right](1-x)^b$$

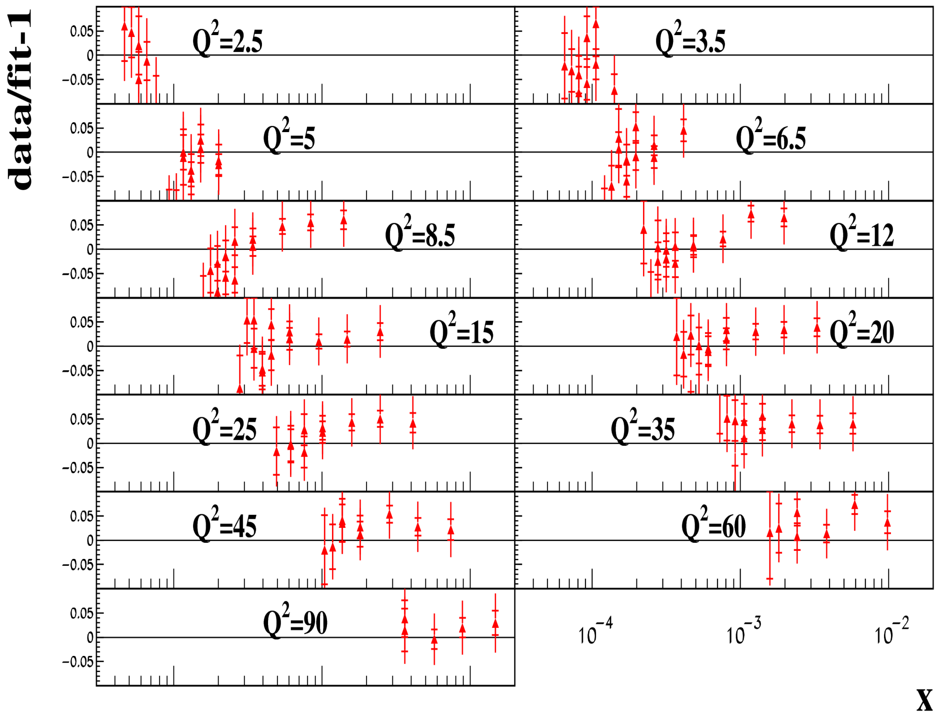
$$xu_V(x) = exp\left[a \ln x(1+\gamma_1 x+\gamma_2 x^2+\gamma_3 x^3)\right](1-x)^b$$

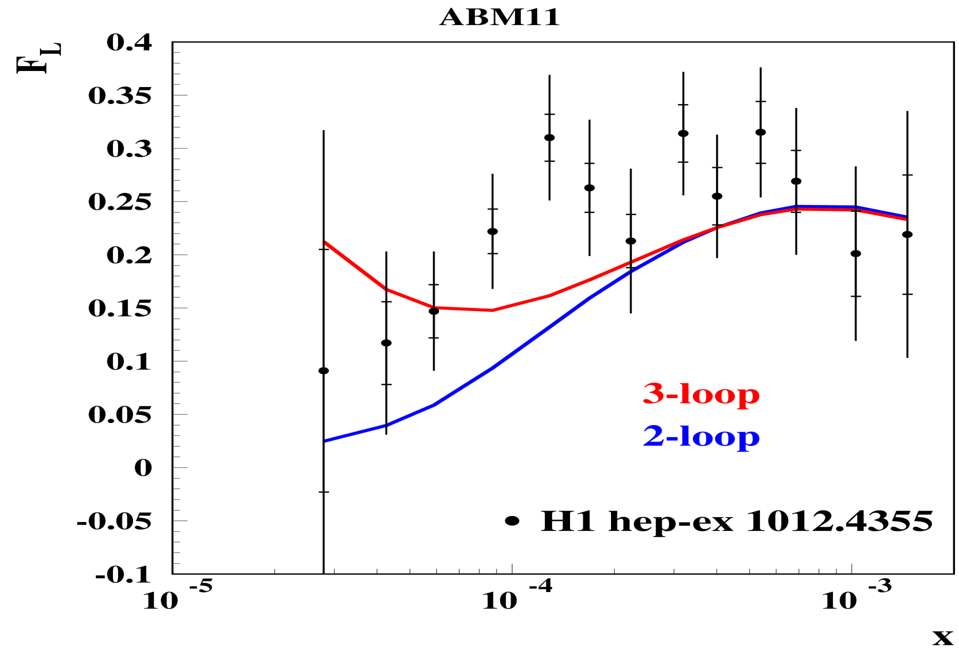
- χ^2/NDP=1.1, with account of the systematic error correlations (114 sources). Slightly worse for the small-Q part, the same observed in the model-independent fit

sa, Blümlein, Moch [hep-ph 1007.3657]

$m_c(m_c)$=1.27±0.08 GeV $m_b(m_b)$=4.19±0.13 GeV (PDG '10)

F_L at small x





The data prefer quite big 3-loop corrections to F_L at small x

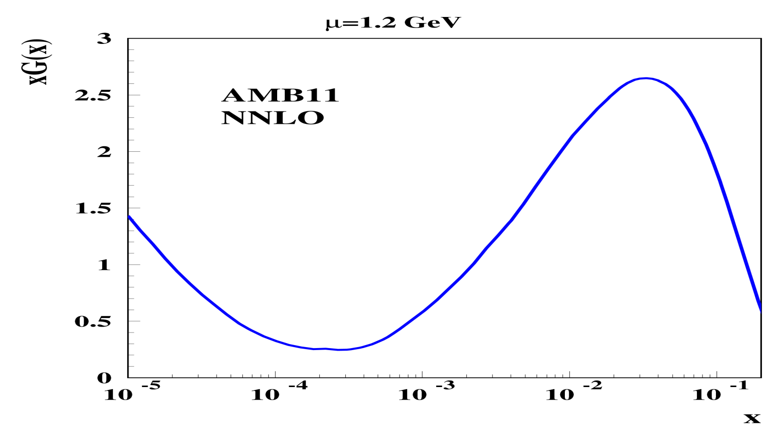
Moch, Vermaseren, Vogt PLB 606, 123 (2005)

- The low-energy H1 data are quite sensitive to F_L at small x and Q

H1 Collaborations hep-ex 1012.4355

- The data can be easily accommodated in the fit: the value of χ^2/NDP=1.05; no clear sign of the collinear evolution violation

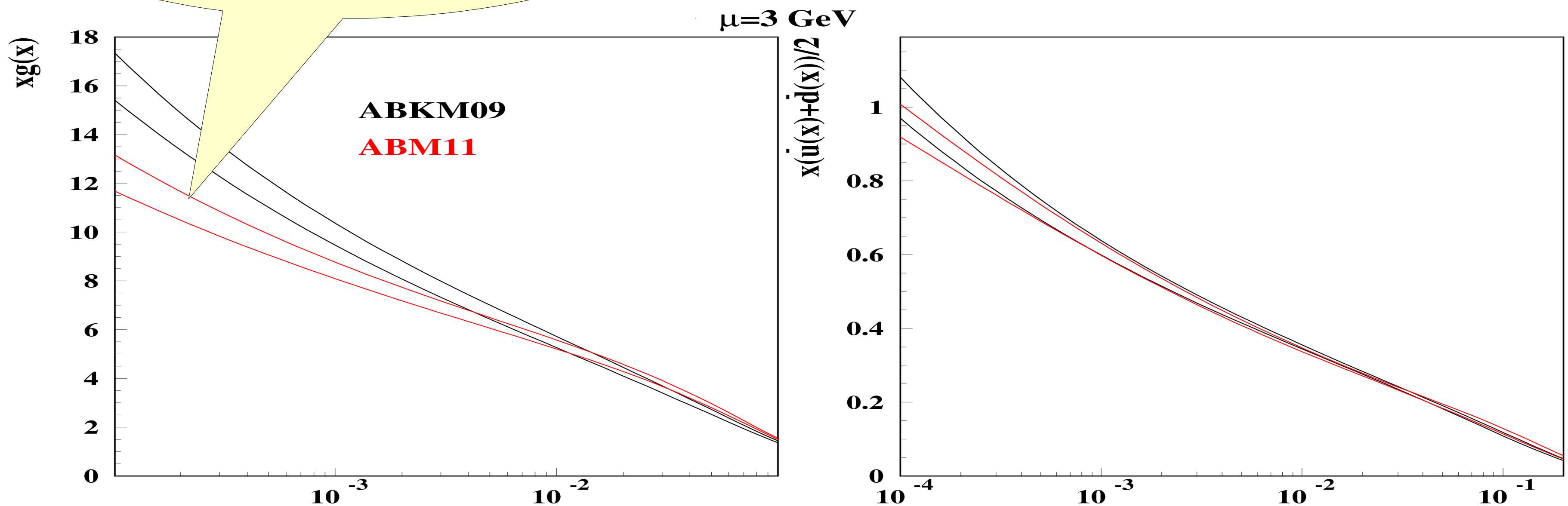
- Positive small-x gluons are preferred by the data at low scale



ABM11 PDFs

Impact of new inclusive HERA data:
normalization and shape

ABM11 = ABKM09
+ HERA inclusive combined data
+ H1 low-energy data
+ 3-loop correction to F_L
+ running-mass definition

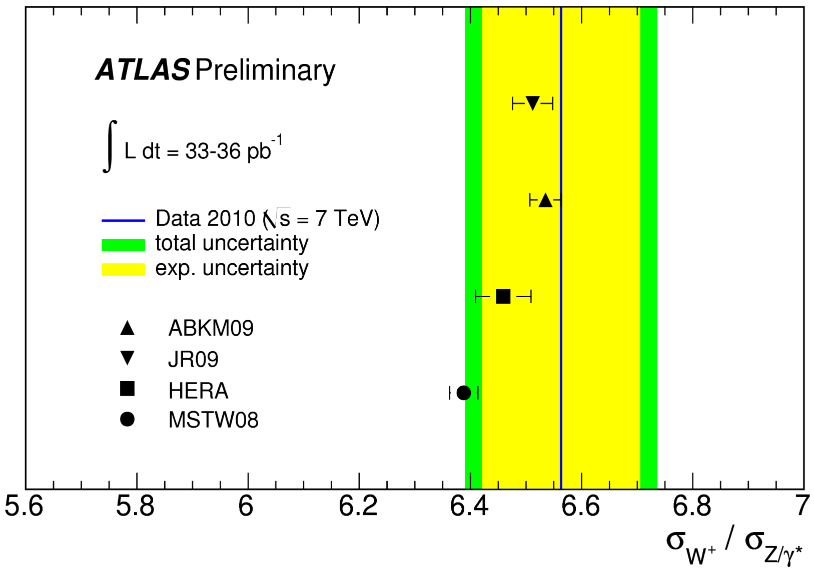


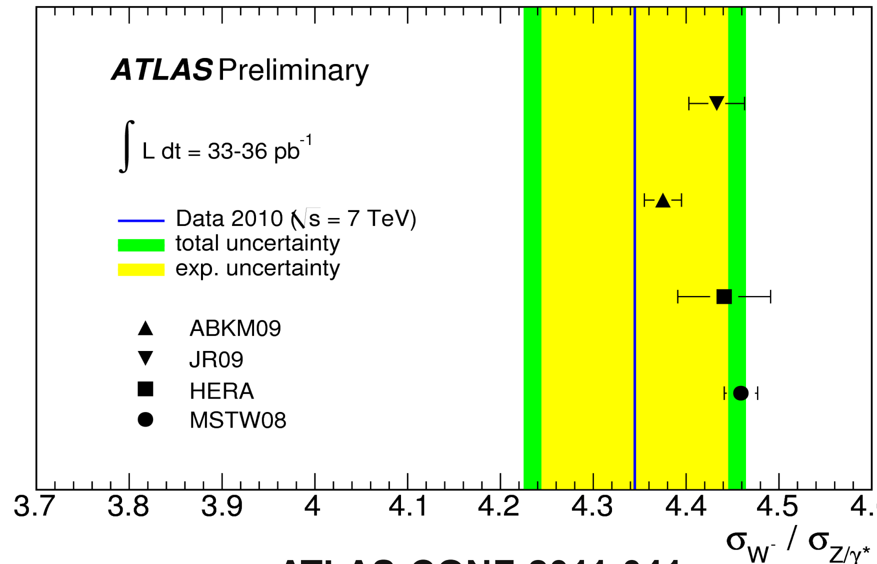
	$\alpha_s(M_z)$
ABKM09	0.1135(14)
ABM11	0.1134(11)

The value of χ^2/NDP=3318/2968=1.1

The perfect stability of α_s is somewhat accidental

NNLO benchmarks





The luminosity uncertainties cancel in the ratio

ATLAS-CONF-2011-041

	σ(W+) (nb)	σ(W-) (nb)	σ(Z) (nb)	σ(M_H=165 GeV) (pb)
ABKM09				
Tevatron	26.1(3)		7.69(8)	0.25(2)
LHC7	58.9(9)	39.4(6)	28.4(5)	7.05(23)
ABM11				
Tevatron	26.4		7.8	0.24
LHC7	58.8	39.6	28.4	7.19

The massive OMEs with the running-mass definition are used to generate 4- and 5-flavor PDFs

Impact of the jet data on gluons

- The NNLO corrections to jet production are cumbersome (non-trivial subtraction of the IR singularities), only the e+e- case has been solved recently. (cf. talk by Sven Moch)

Weinzierl, Gehrmann-De Ridder, Gehrmann, Glower, Heinrich

NLO evolution + NLO coefs
- consistent fit

NNLO evolution + NLO coefs
- the PDF evolution more accurate
- the PDFs ready for the HO calculations

RunII Tevatron data checked wrt ABKM09:

D0 midpoint inclusive (R=0.7)

PRL10, 062001 (2008)

D0 midpoint (R=0.7)

PLB 693, 531 (2010)

CDF K_T (D=0.7)

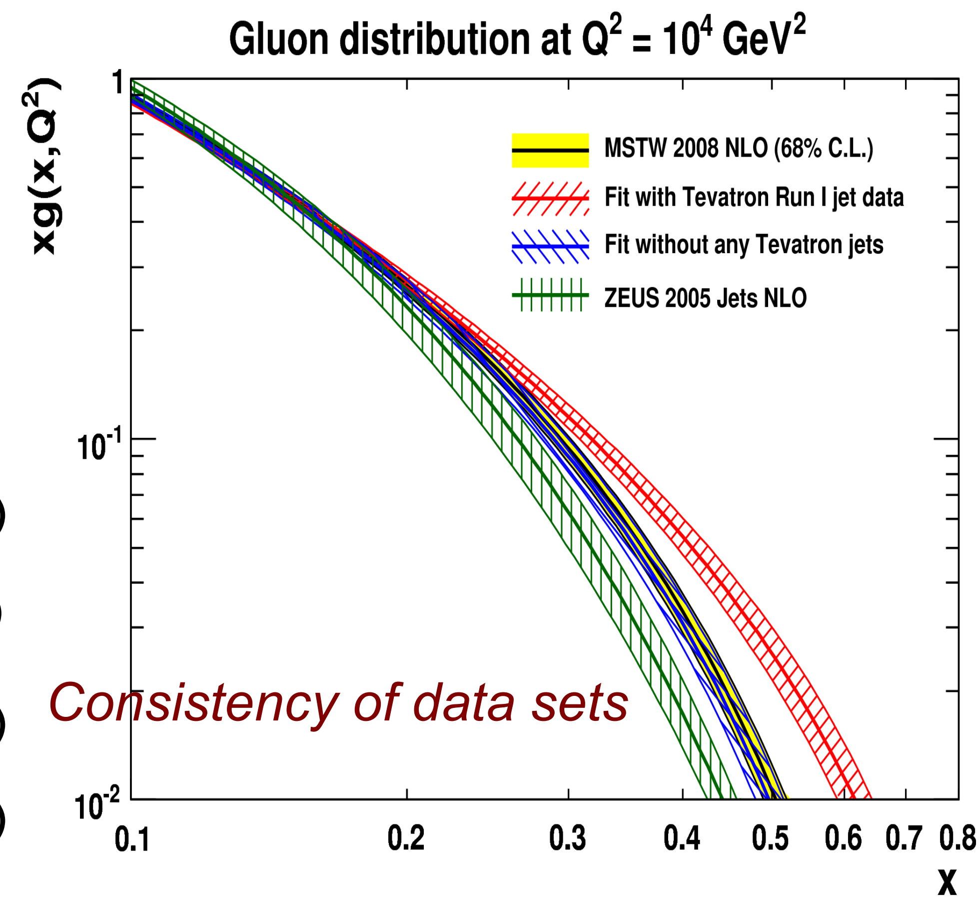
PRD75, 092006 (2007)

CDF midpoint (R=0.7)

PRD 78, 052006 (2008)

FastNLO is used to employ NLO corrections.

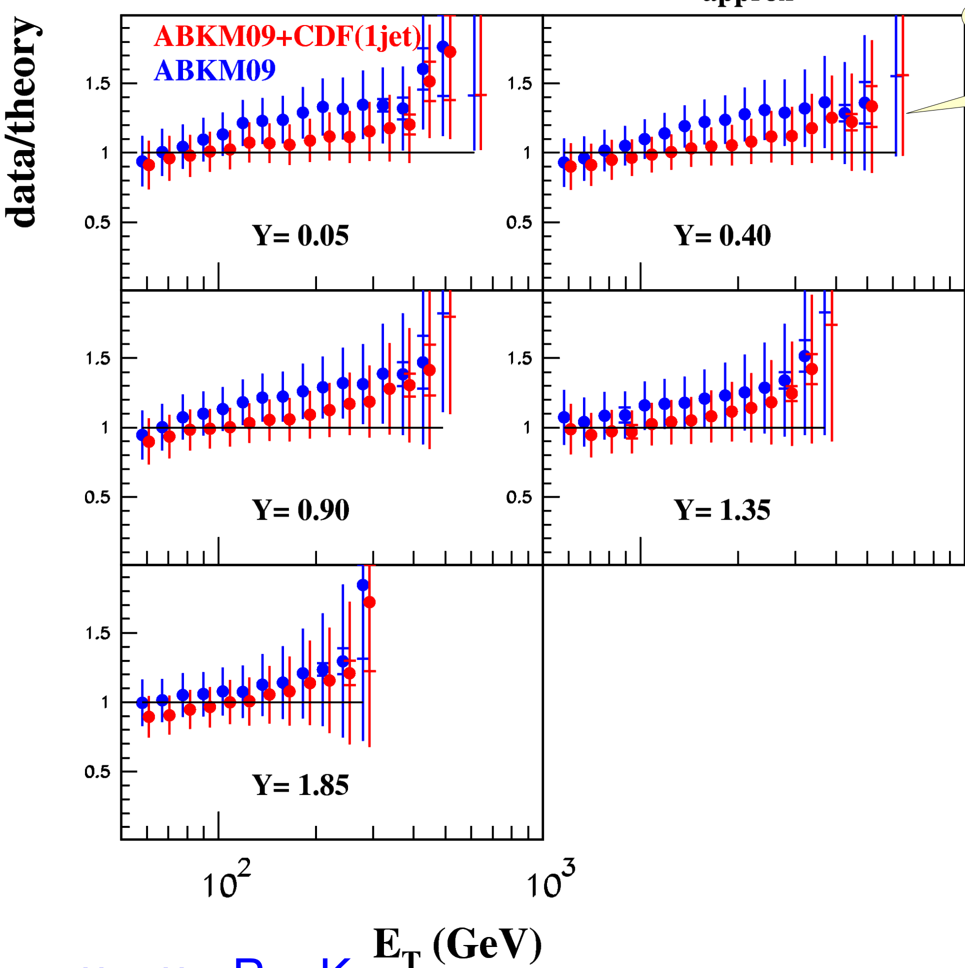
Kluge, Rabberitz, Wobbisch [hep-ph 0609285]



MSTW Collaboration EPJC 63, 189 (2009)

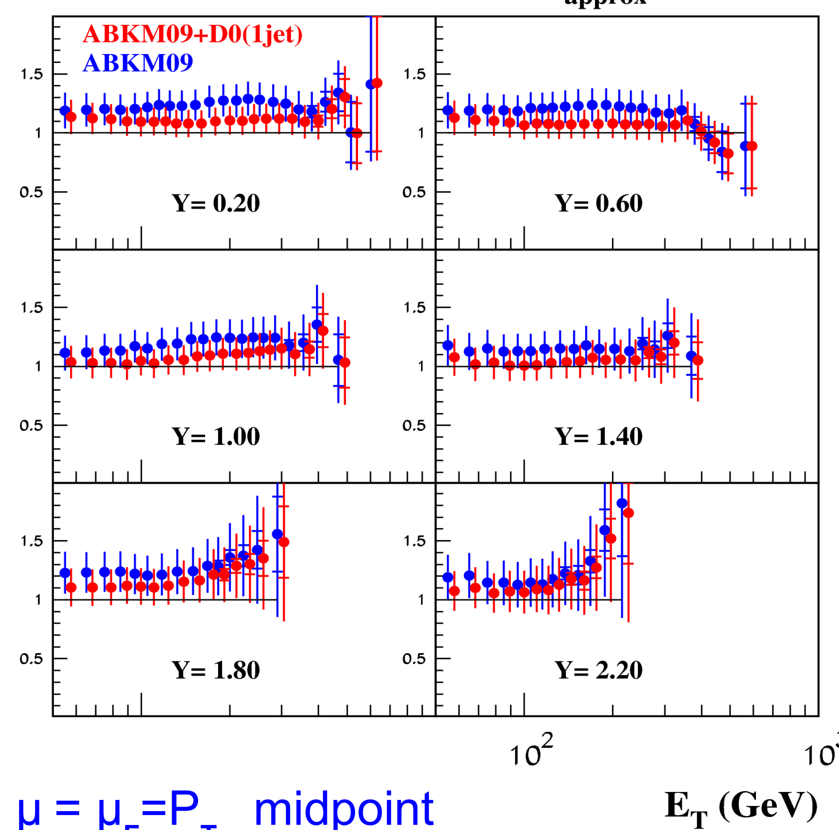
D0 and CDF inclusive data

CDF(1jet) - NNLO(evol) + NNLO$_{approx}$(coeff)



dominated by quark-quark scattering

D0(1jet) - NNLO(evol) + NNLO$_{approx}$(coeff)

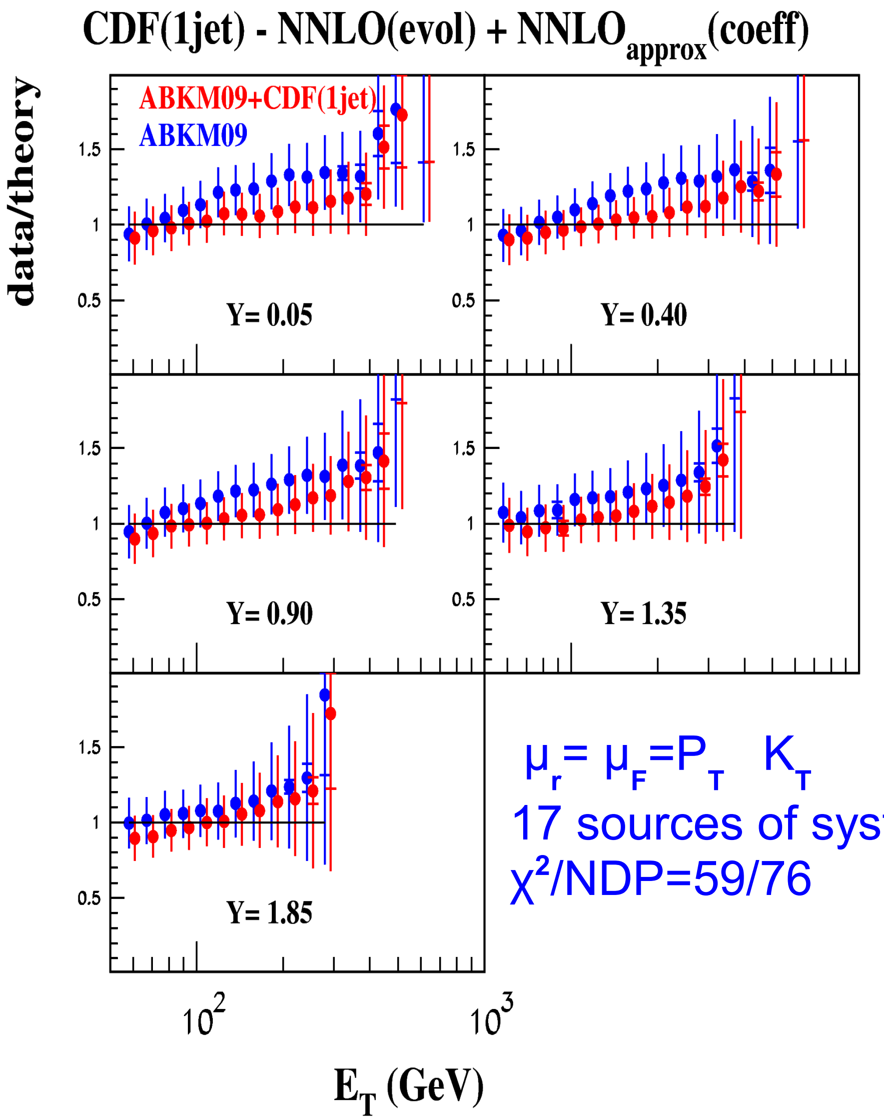


$\mu_r = \mu_F = P_T$ K_T
17 sources of systematics
χ^2/NDP=59/76

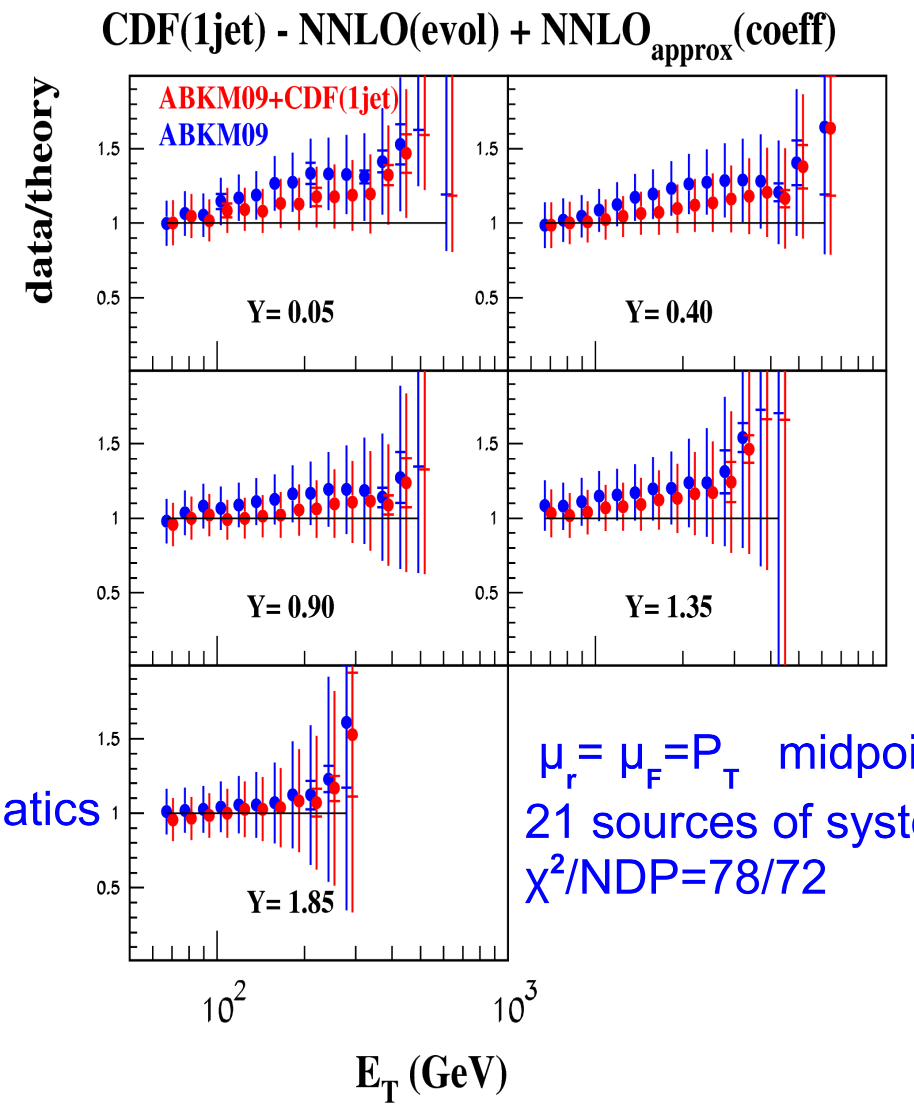
$\mu_r = \mu_F = P_T$ midpoint
24 sources of systematics
χ^2/NDP=103/110

For the D0 data the discrepancy with the ABKM predictions can be explained by the missing NNLO K-factor of 20-30%. For the CDF data the slope in data is different; the agreement at large E_T can be hardly improved.

CDF: k_T and cone data



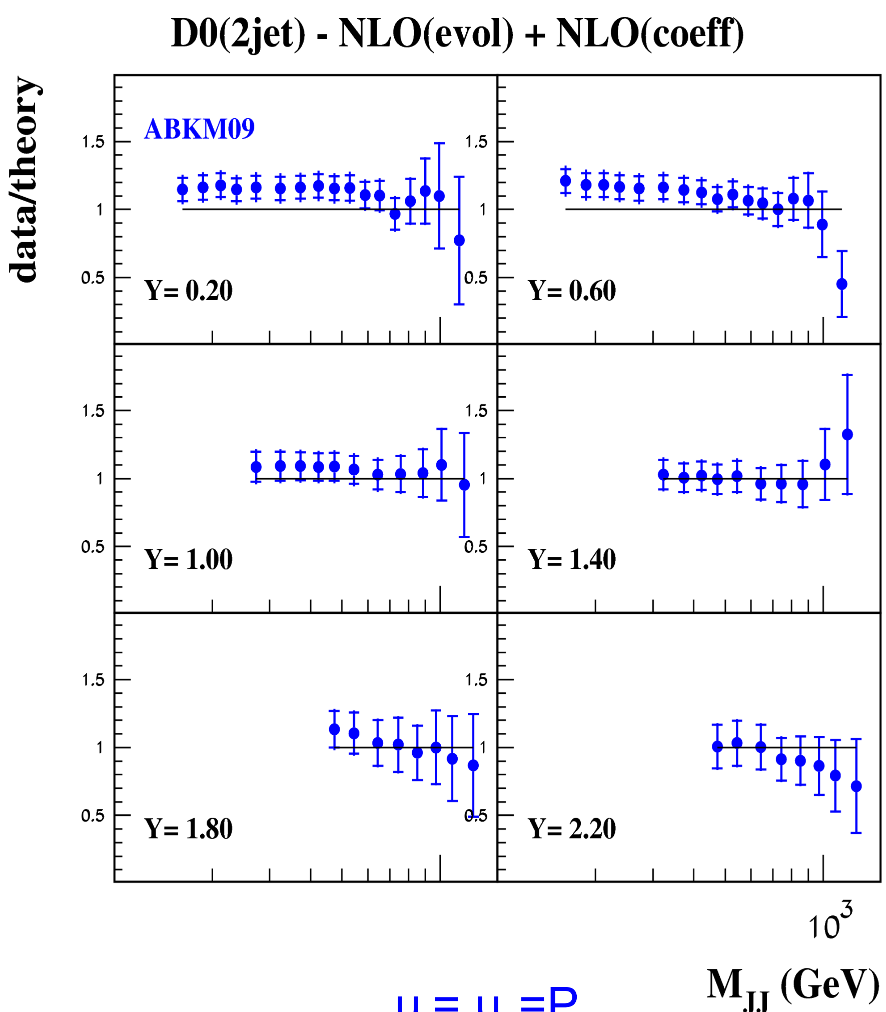
$\mu_r = \mu_F = P_T$ K_T
17 sources of systematics
χ^2/NDP=59/76



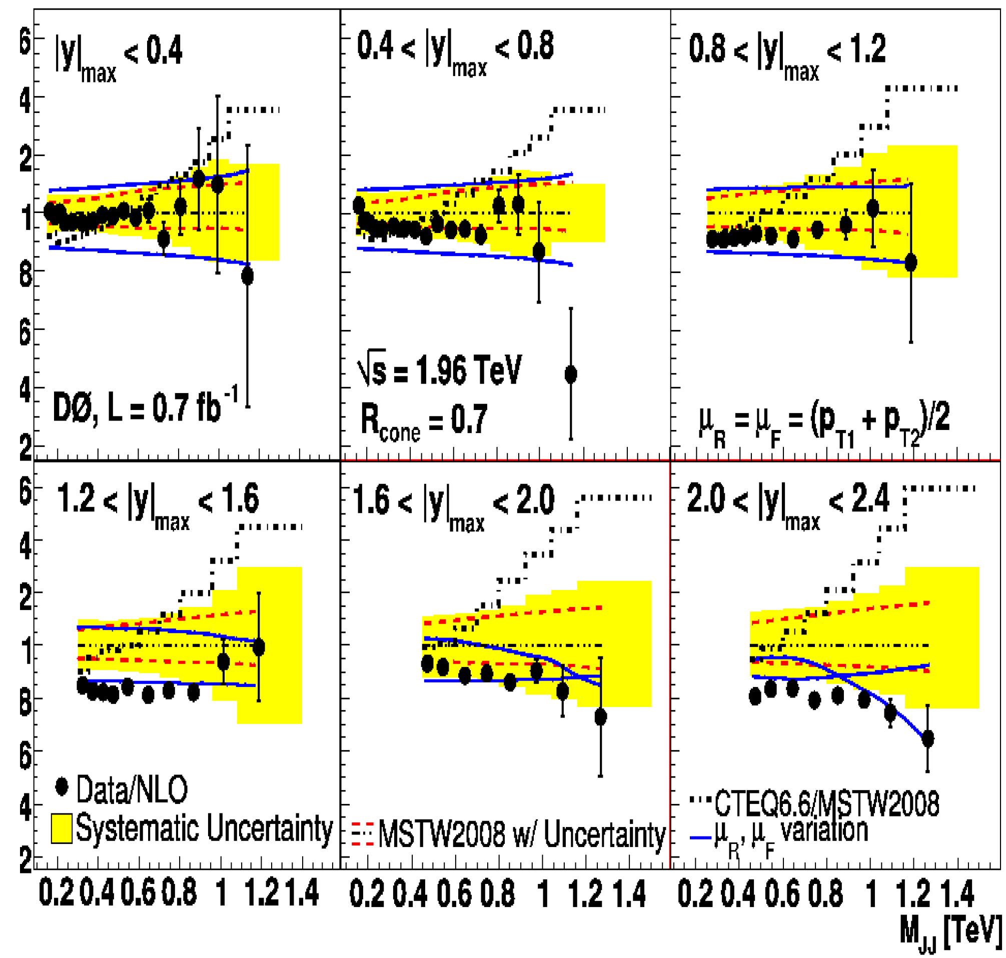
$\mu_r = \mu_F = P_T$ midpoint
21 sources of systematics
χ^2/NDP=78/72

The cone data (predictions) go lower(higher) than the k_T ones → better agreement with the ABKM, lower value of α_s is preferred in the combined fit

D0 dijet data in the NLO fits



$\mu_r = \mu_F = P_T$

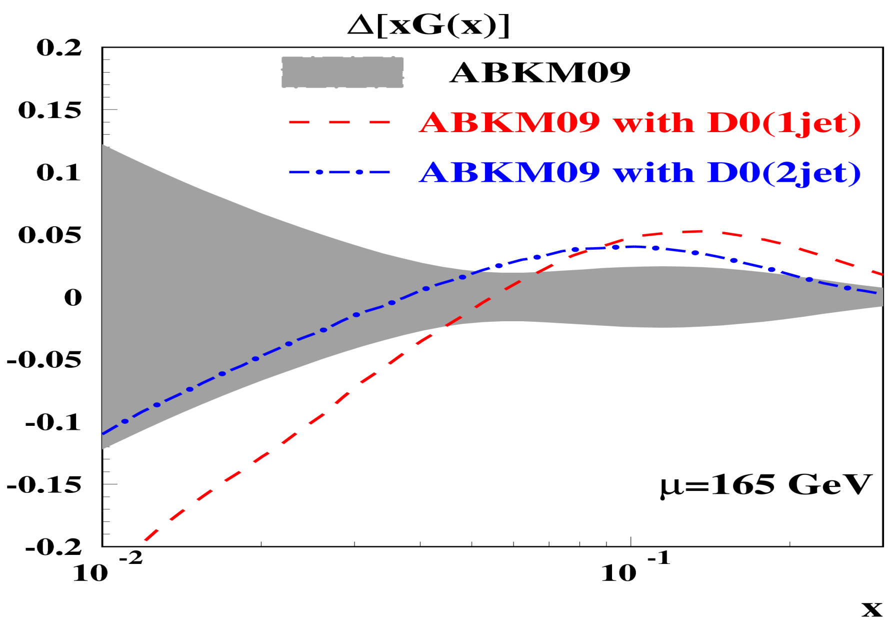


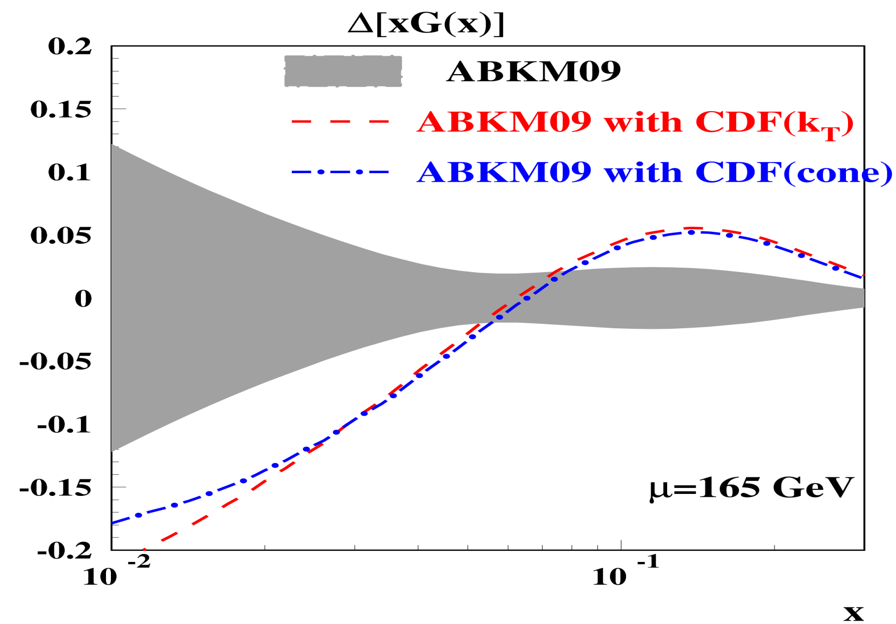
D0 Collaboration PLB 693, 531 (2010)

The NLO ABKM09 **predictions** describes jet data better than the fits based on the Tevatron data? → this is not problem of PDFs, rather problem of the data.

The Tevatron jet data are not completely understood

Gluons at small x and Higgs c.s.

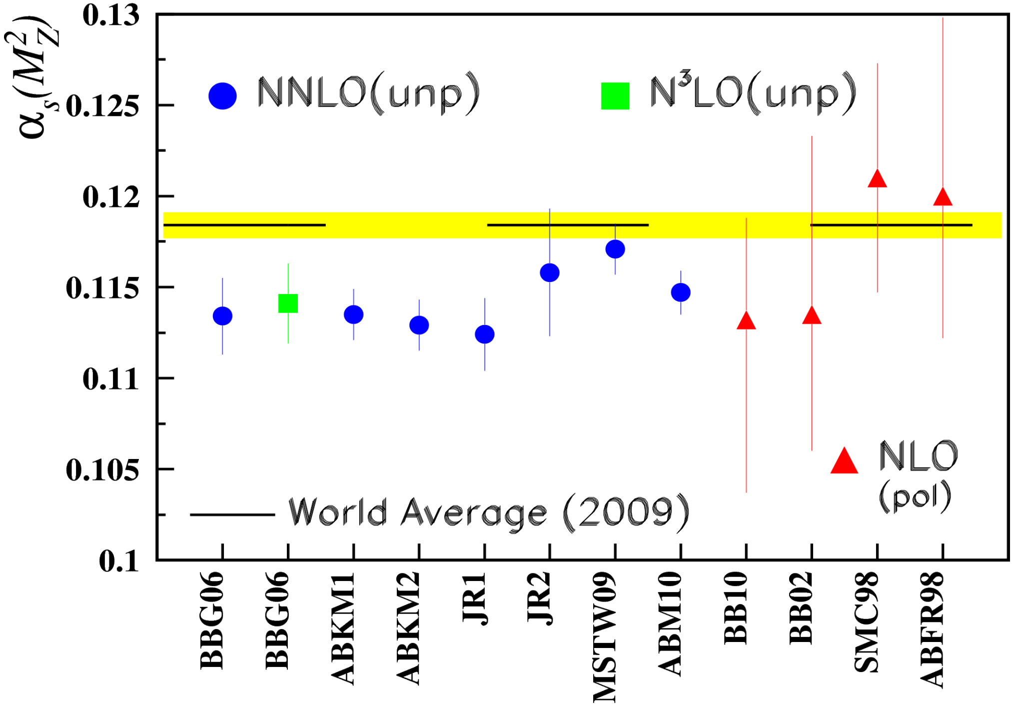




	$\alpha_s(M_Z)$(NNLO)	$\sigma(M_H$=165 GeV) (pb)	
		Tevatron	LHC7
ABKM:	0.1135(14)	0.25(2)	7.1(2)
+ D0(1jet):	0.1149	0.30	7.3
+ D0(2jet):	0.1144	0.28	7.3
+ CDF/k_T	0.1141	0.29	7.15
+ CDF/cone(prel.)	0.1130	0.28	7.0

- The Tevatron jet data pull the Higgs up by 1-2σ, depending on the data set
- For the LHC7 relative effect is smaller, than for the Tevatron
- *The value of α_s is still "small"*

PDFs and α_s



Blümlein, Böttcher NPB 841, 205 (2010)

- Many important hadronic processes i.e. Higgs and top-quark production are $\sim\alpha_s^2$.
- The gluon distribution is correlated with α_s $\rightarrow$ effect is accumulated.
- The value of α_s from DIS *(mostly defined by the non-singlet part)* is about 3σ lower than the world average of 2009.

Bethke EPJC 64, 689 (2009)

From the Tevatron jet data

$\alpha_s(M_z)=0.1161\pm0.0045$ (NLO)

D0 Collaboration [hep-ex 1006.2855]

$\alpha_s(M_z)=0.1135\pm0.0014$ (NNLO)

sa, Blümlein, Klein, Moch PRD 81, 014032 (2010)

$\alpha_s(M_z)=0.1171\pm0.0014$ (NNLO)

MSTW Collaboration EPJC 64, 653 (2009)

From the world e+e- data on trust

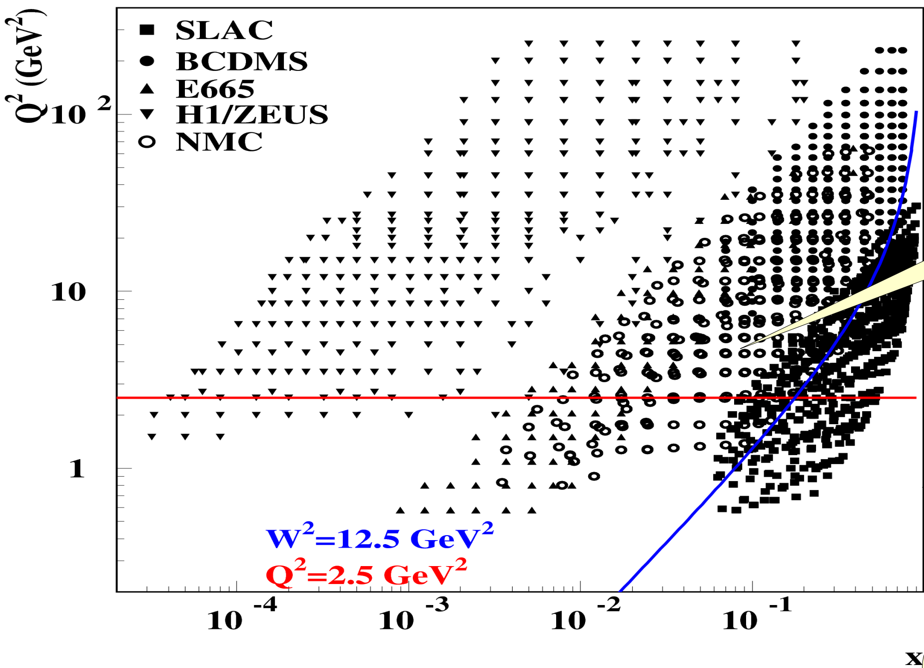
$\alpha_s(M_z)=0.1135\pm0.0002(\text{exp.})\pm0.0005(\text{had.})\pm0.0009(\text{pert..})$ (NNLO)+*power corr.*

Abbate, Fickinger,Hoang, Mateu, Steward [hep-ph 1006.3080]

Recent results are in nice agreement with the DIS values

The difference in α_s makes difference of 30-40% in the Higgs c.s. at Tevatron

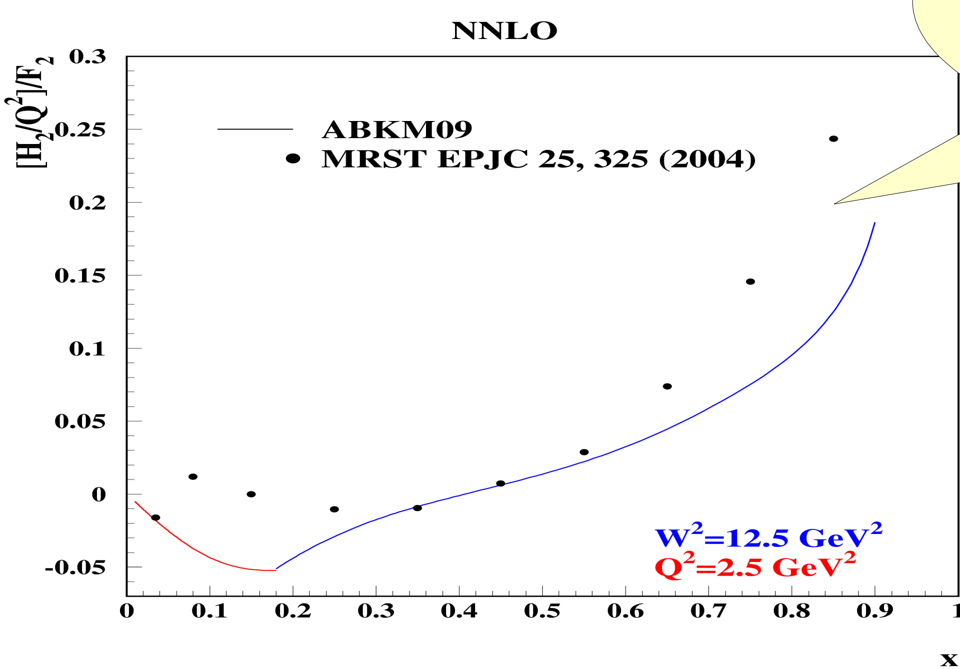
High-twist terms in DIS



Is not removed with the “safe” cut on W

At small Q and /or W the high-twist (HT) terms give substantial contribution. One can try to get rid of them with a “safe” cut on W:

The selection of W_{at} is unclear due to fluctuations
In the data → the HT terms are essential at the border of kinematics left after the cut

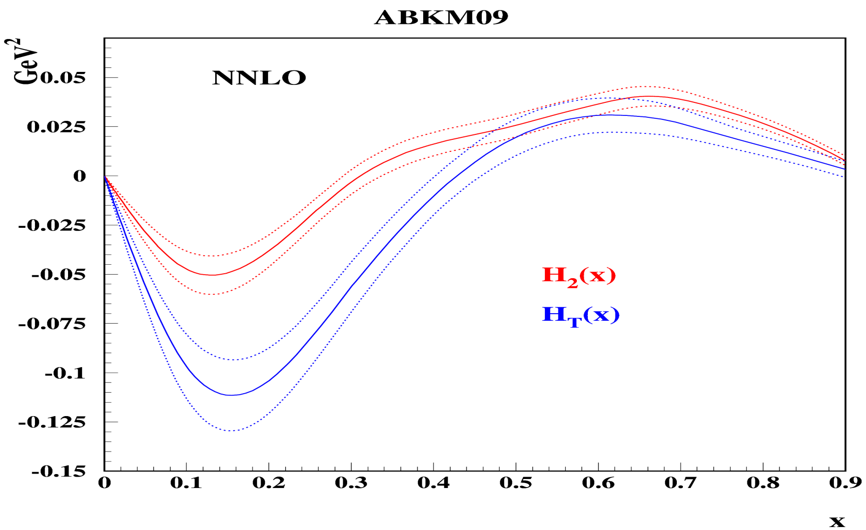


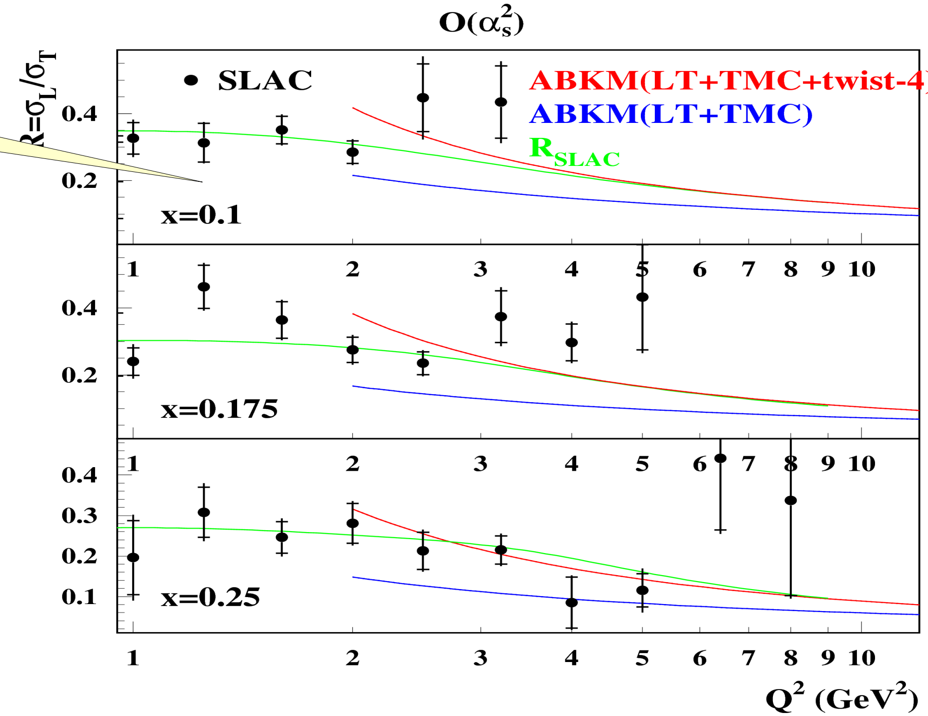
In the ABKM fit the twist-4 terms are fitted simultaneosly with the leading-twist PDFs → consistent separation:

$$F_{2,T} = F_{2,T}\,(LT) + H_{2,T}\,(x)/Q^2$$

Twist-6 terms are necessary?

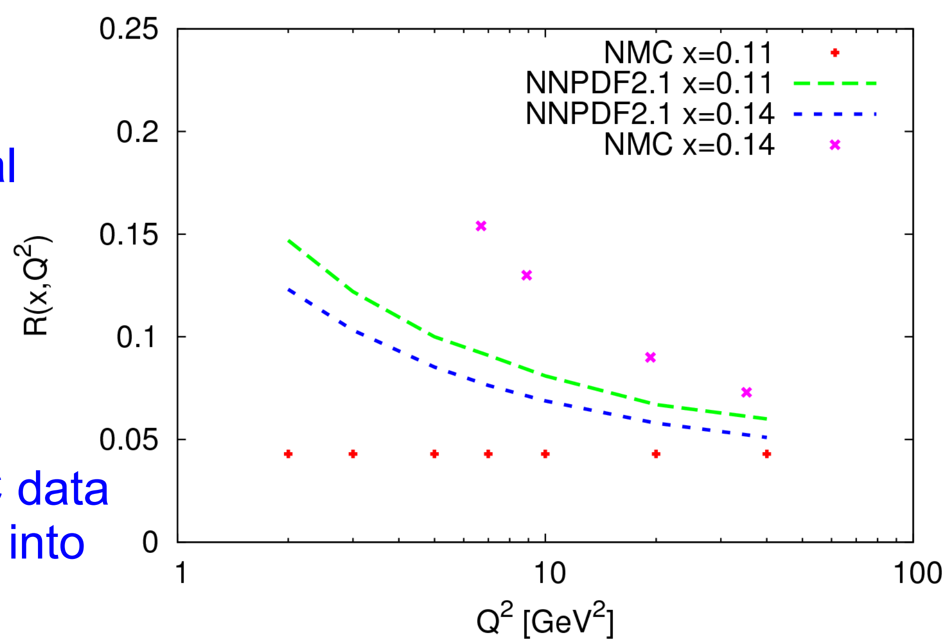
sa, Kulagin, Petti [hep-ph 0710.0124]





At x~0.1 the twist-4 terms in F_T are important:

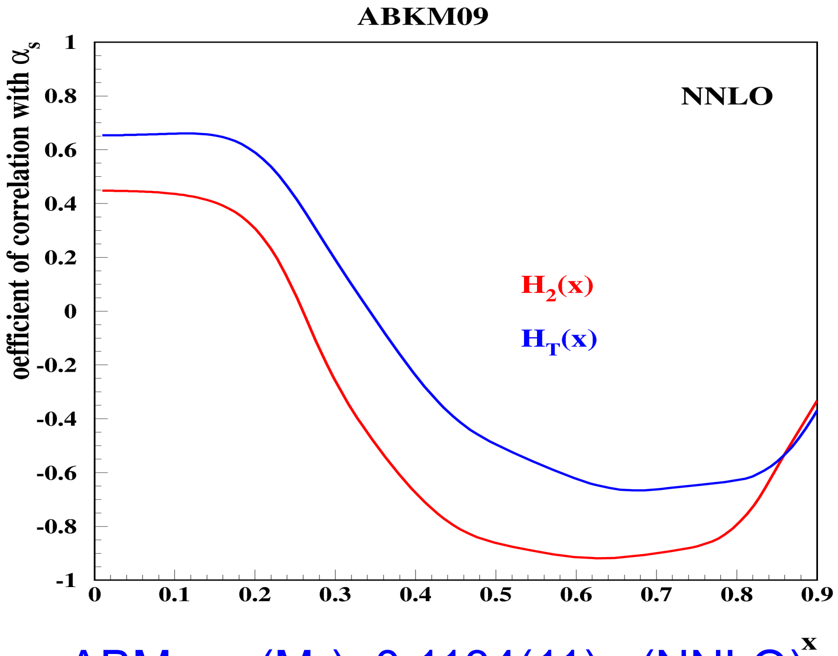
- In the ABKM fit they give about half of the total value of R at the SLAC kinematics
- In the NNPDF fit the leading-twist terms are insufficient to describe the SLAC data
- In the MSTW fit the agreement with the SLAC data on R is good → the twist-4 terms are absorbed into the leading-twist terms?



(courtesy of J.Rojo)

A verification of the SLAC data is highly desirable

Correlation of α_s with twist-4 terms



The value of α_s and twist-4 terms are strongly correlated

- With HT=0 the errors are reduced → no uncertainty due to HTs
- With account of the HT terms the value of α_s is stable with respect to the cuts
- With the HT terms fitted the fit “unstable” with respect to the ansatz

ABM: $\alpha_s(M_z)$=0.1134(11) (NNLO)
(W>1.8 GeV, Q2> 2.5 GeV^2, fitted twist-4 terms in $F_{2,T}$)

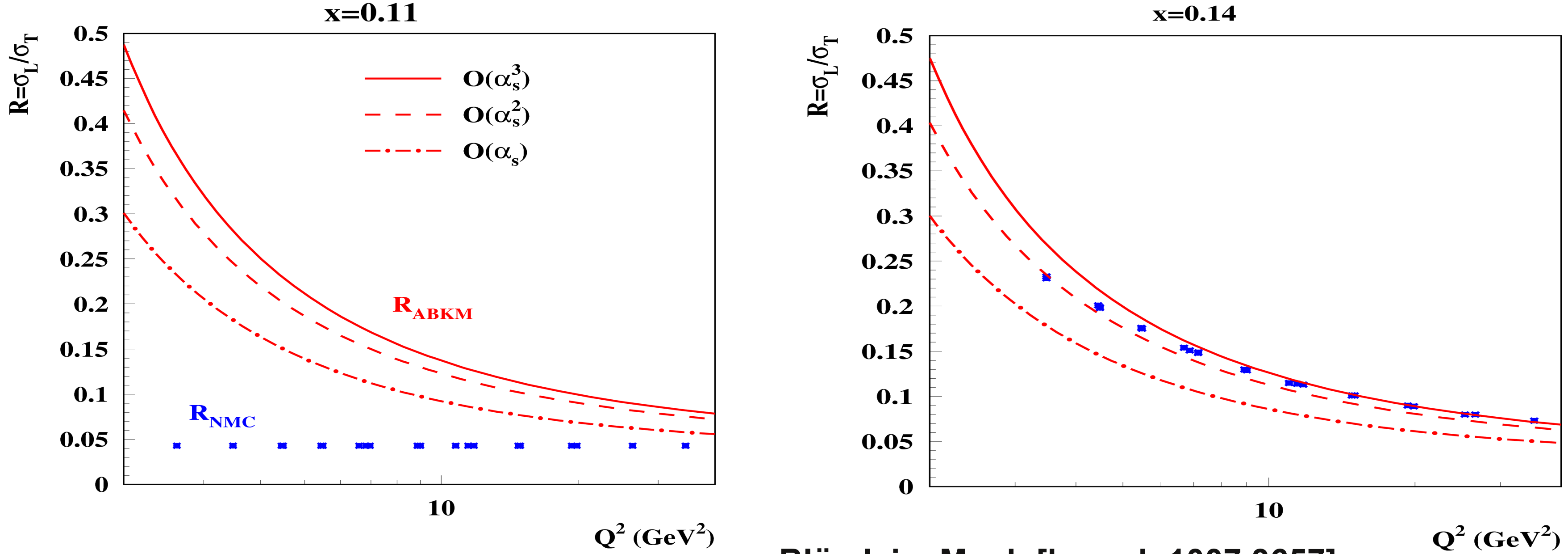
MRST: $\alpha_s(M_z)$=0.1153(20) (NNLO)
(W>15 GeV, Q2> 10 GeV^2, fitted twist-4 terms in $F_{2,T}$)

MRST Collaboration EPJC 35, 325 (2004)

	W^2>12.5 GeV^2 Q^2>2.5 GeV^2	W^2>12.5 GeV^2 Q^2>10 GeV^2
HT fixed	0.1125(7)	0.1125(10)
HT=0	0.1168(7)	0.1143(10)

Very stringent cut is necessary for the fit with HT=0

Value of R and α_S

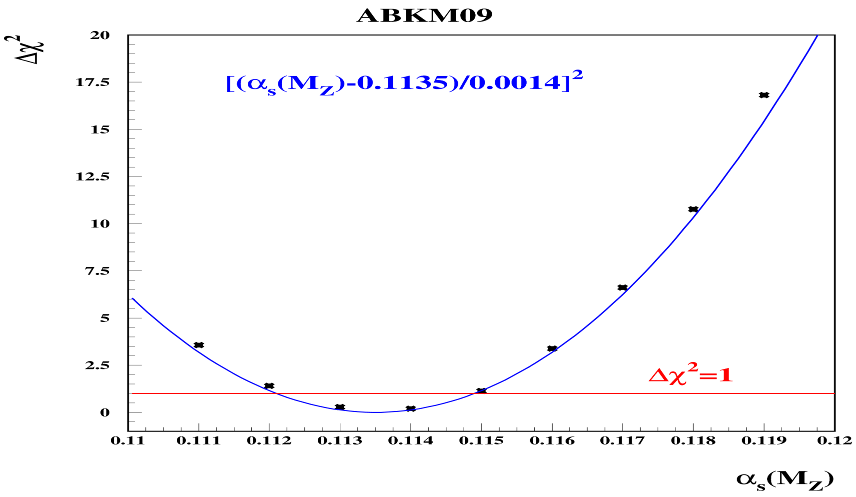


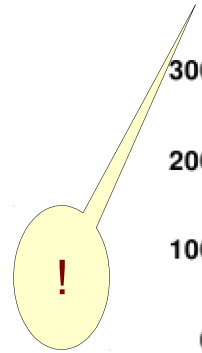
sa, Blümlein, Moch [hep-ph 1007.3657]

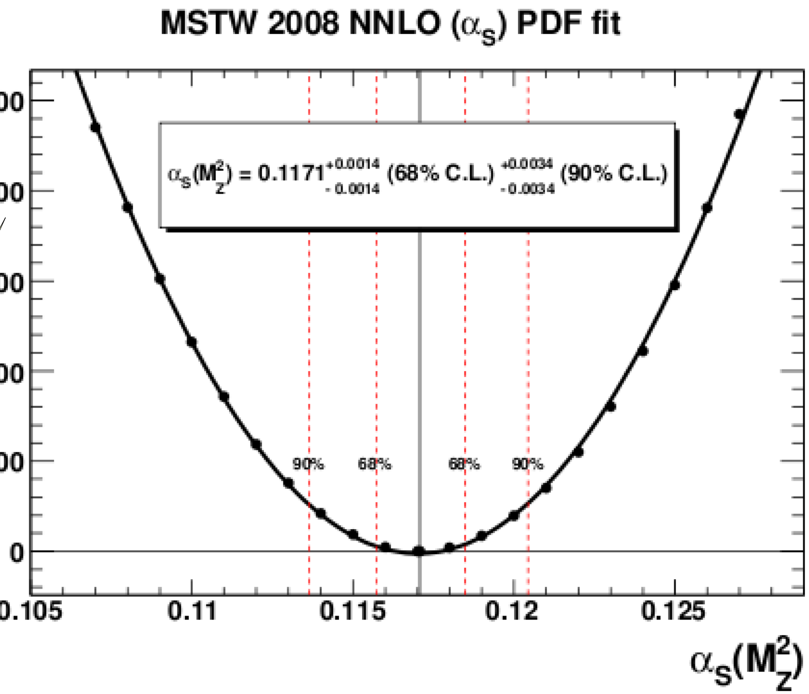
$\alpha_s(M_Z)$	$\alpha_s(M_Z)$ with $\sigma_{\rm NMC}$	$\alpha_s(M_Z)$ with $F_2^{\rm NMC}$	difference
NLO	0.1179(16)	0.1195(17)	$+0.0016 \simeq 1\sigma$
NNLO	**0.1135(14)**	0.1170(15)	$+0.0035 \simeq 2.3\sigma$
NNLO $+F_L$ at $O(\alpha_s{}^3)$	0.1122(14)	0.1171(14)	$+0.0050 \simeq 3.6\sigma$

- With a smooth model of R the value of α_s is smaller
- Effect rises from NLO to NNLO

MSTW observes smaller shift: $\alpha_s(M_z)$=0.1171 $\rightarrow$ 0.1168 (NNLO)



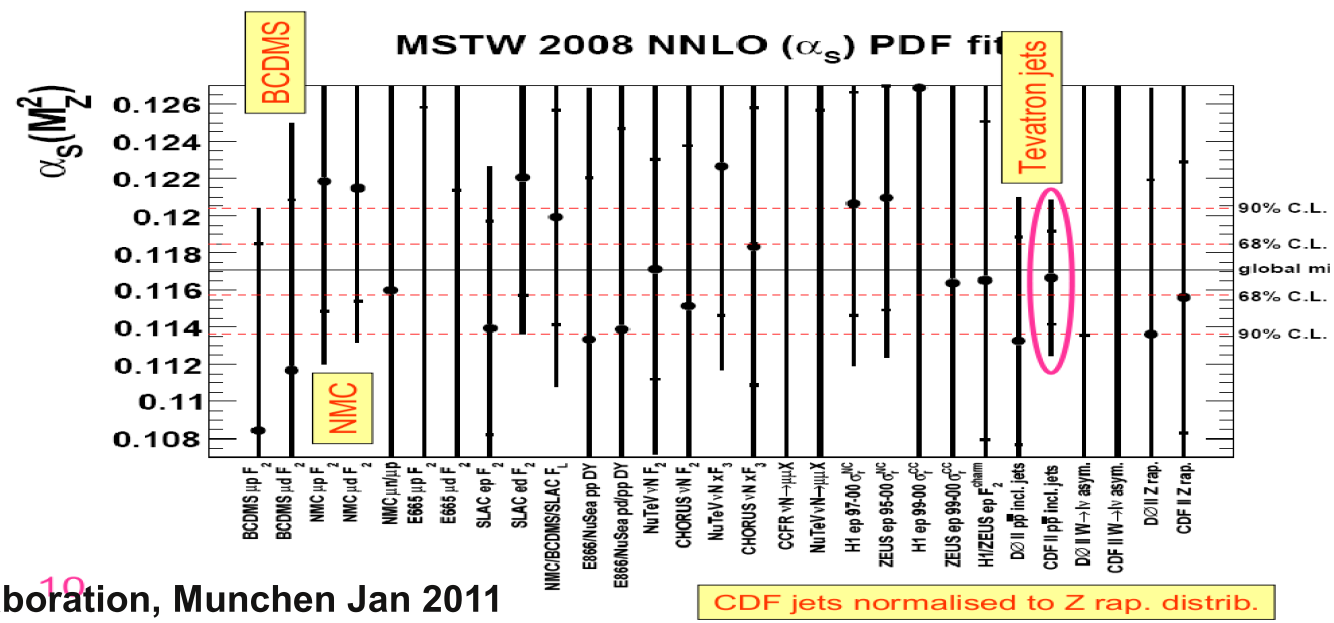




MSTW Collaboration EPJC 64, 653 (2009)

In the MSTW fit α_s is more constrained:

- the high-twist terms set to 0
- impact of the jet data
- .....? → further comparisons are necessary



Summary

- With the improved treatment of the heavy-quark contribution and new HERA data added
  - the "small" ABKM value of α_s is confirmed $\alpha_s(M_z)=0.1134(11)$ (NNLO)
  - the Higgs c.s. at Tevatron (LHC) moves down(up) by less than 1σ

  (*the consistent treatment of the fixed-target DIS data is important*)

- The "small" value of the α_s is confirmed in the approximate NNLO fit with the Tevatron jet data included:

  $\alpha_s(M_z)=0.1135(14) \rightarrow 0.1130 - 0.1149$ (NNLO)

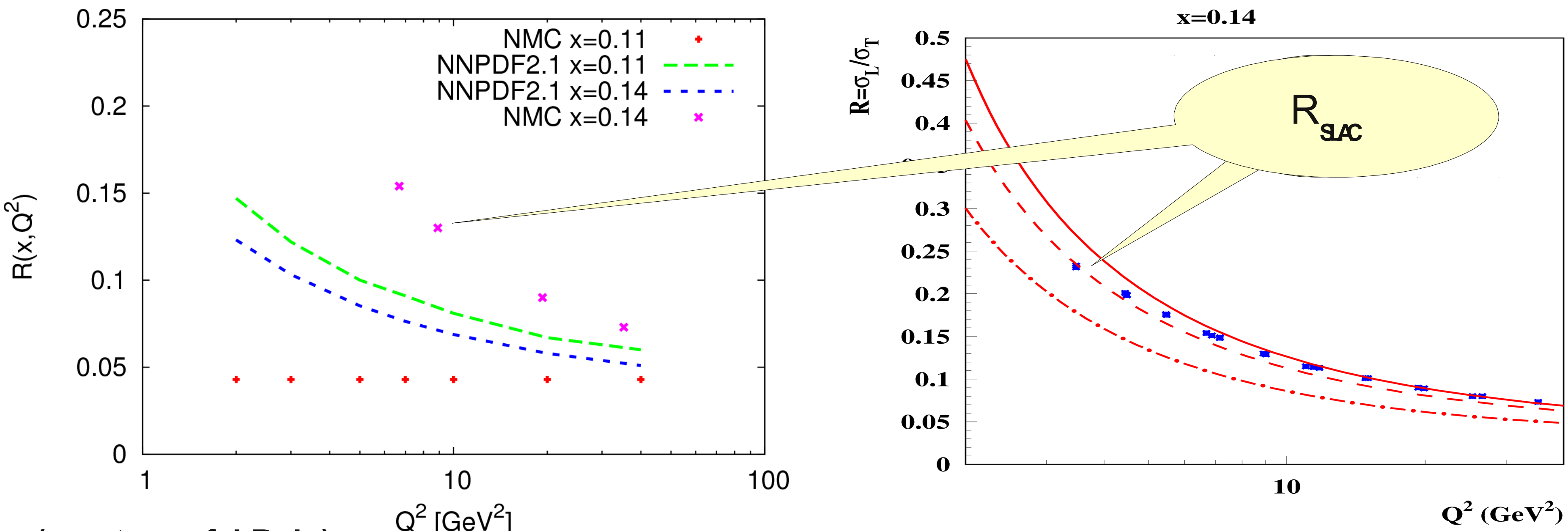
  depending on the data set used

  The Higgs cross section can go up by ~1-2σ

  – *scale sensitivity?* → no NNLO corrections

NNPDF reanalysis

NNPDF Collaboration   hep-ph 1102.3182



(courtesy of J.Rojo)

sa, Blümlein, Moch [hep-ph 1101.5261]

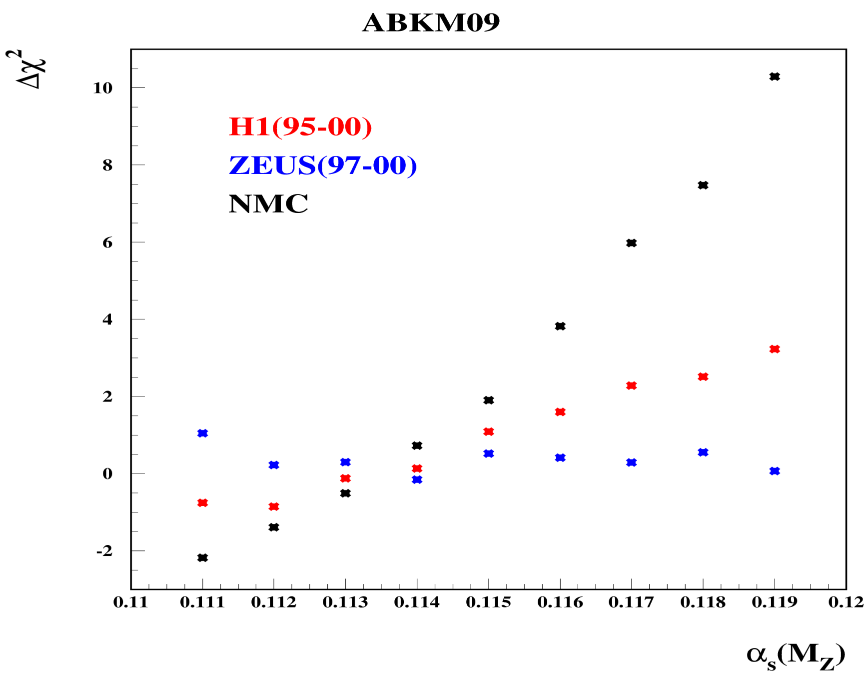
- The NNPDF model of R doesn't match with the SLAC parameterization – *the high-twist terms are essential*

$$R^{\text{fit}} = \frac{b_1}{\ln(Q^2/\Lambda^2)}\Theta(x,Q^2) + \frac{b_2}{Q^2} + \frac{b_3}{Q^4+0.3^2},$$

Whitlow et al. PLB 250, 193 (1990)

- The published NNPDF analysis is performed in the NLO
- The correlation between α_s and gluons is not considered by NNPDF

More detailed comparison is necessary


ABKM09
$\Delta\chi^2$
10
8
6
4
2
0
-2
H1(95-00)
ZEUS(97-00)
NMC
0.11
0.111
0.112
0.113
0.114
0.115
0.116
0.117
0.118
0.119
0.12
$\alpha_s(M_Z)$